Ceramic Wall Flow Filter for Particulate Emission Reduction of Petrol Engines

CAMBRIDGE PARTICLE MEETING

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24th May 2013

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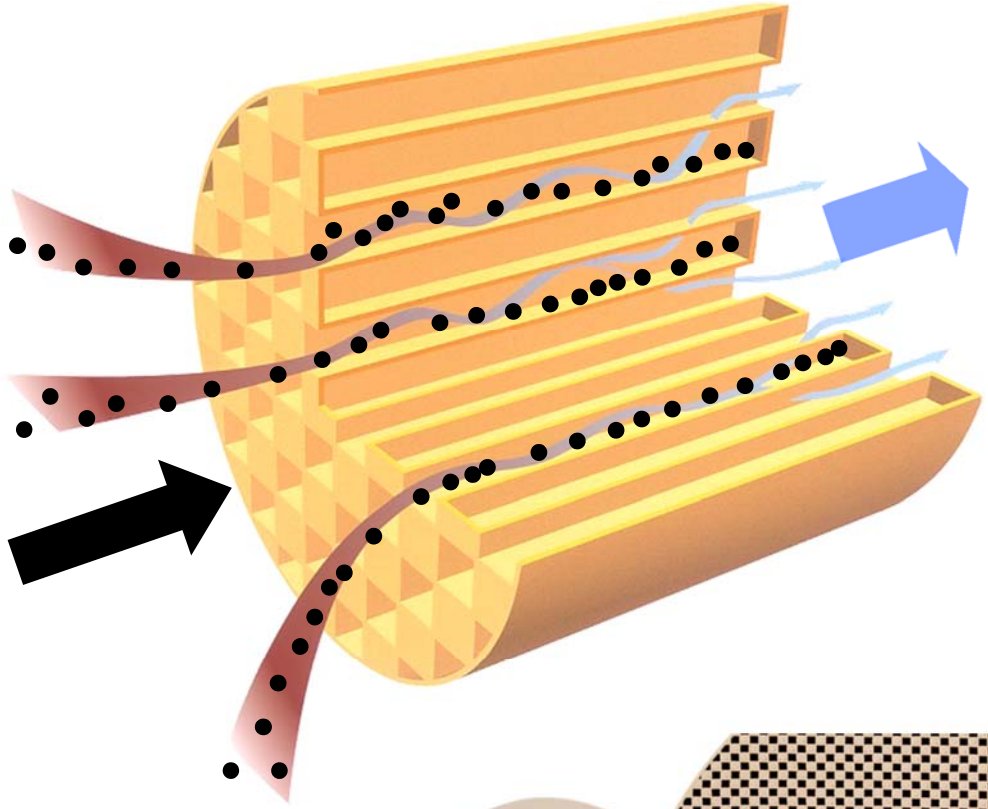
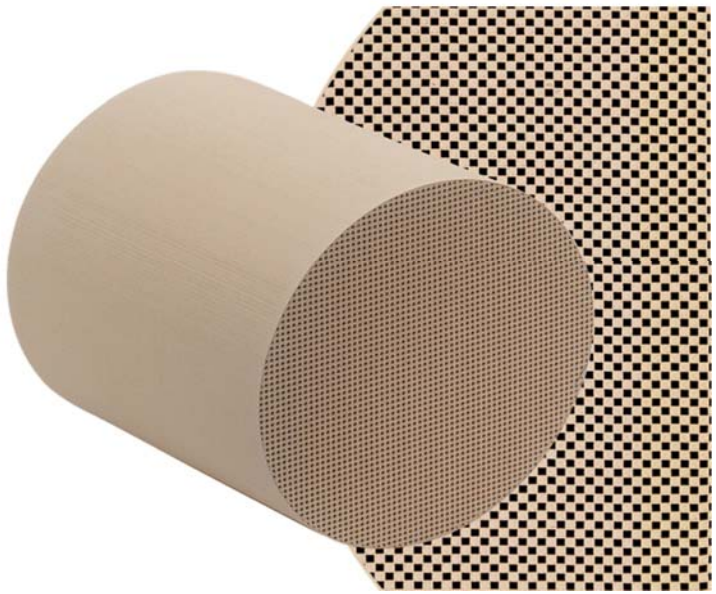
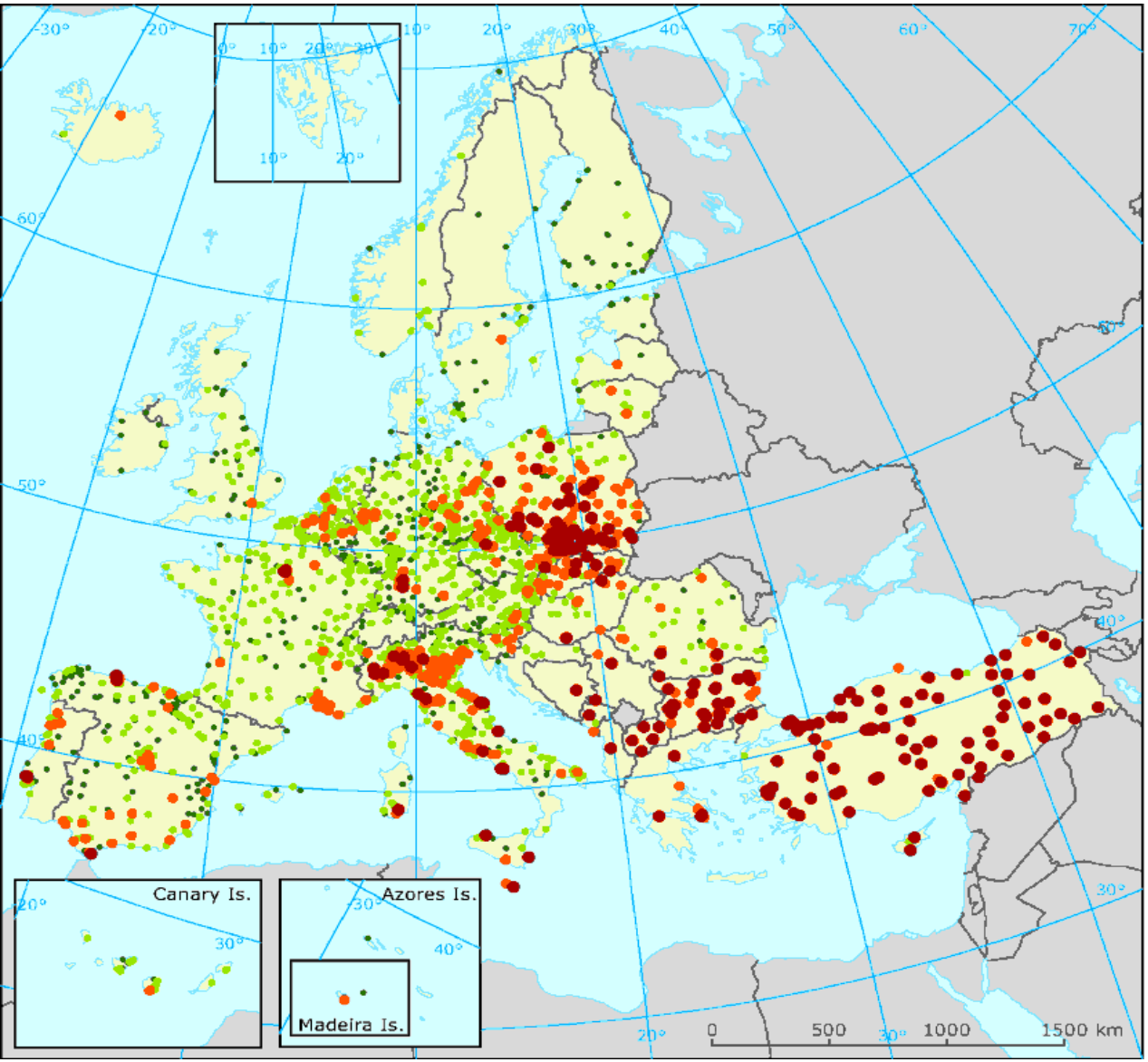
  - Background
  - Legislation
- GPF* Concepts
  - System Layout
  - Non-catalysed Applications
  - Catalysed Applications
- Conclusion





* GPF: Gasoline Particulate Filter

Annual Mean Air Quality in EU on Particulate Matter



Annual mean particulate matter (PM_{10}) 2010, based on daily average with percentage of valid measurements ≥ 75 % in µg/m³

- ≤ 20
- 20–31
- 31–40
- > 40
- Countries/regions not included in the data exchange process

PM 10 Emission ● > 40 µg/m³

Source: European Environmental Agency (EEA) 2012

Some European areas show high Particulate Matter concentrations.

Trend of Particulate Matter Regulation (PC/LDV)

	2013	2014	2015	2016	2017	2018	2019	2020	2021…	…2025
	Euro5 NEDC Diesel: PM 5.0 mg/km Gasoline (DI): PM 5.0 mg/km		**Euro6b** NEDC Diesel: PM 4.5 mg/km PN 6 x 10^{11} #/km Gasoline (DI): PM 4.5 mg/km ***PN6 x 10^{12} #/km***		***9/2017***	**Euro6c** ***WLTC + RDE*** Diesel/Gasoline (DI): PM 4.5 mg/km ***PN6 x 10^{11} #/km*** All: ***CO_2 120 g/km***			**Euro7?** ***WLTC + RDE*** All: ***CO_2 95 g/km***	
	LEV2 FTP Diesel/Gasoline(DI): PM 10.0 mg/mile		**LEV3** FTP Diesel/Gasoline (DI): ***PM 6.0 mg/mile***			**LEV3** FTP Diesel/Gasoline (DI) Phase-in (%): ***PM 3.0 mg/mile***			**LEV3** FTP All: PM 3.0mg/mile	**LEV3** FTP All %: PM ***1 mg/mile***
	Post New Long Term JC08(hot) + JC08(cold) Diesel: PM 5.0 mg/km Gasoline (GDI): PM 5.0 mg/km					**Post Post New Long Term** JC08(hot) + JC08(cold) ? Diesel: PM 5.0 mg/km ? Gasoline (GDI): PM 5.0 mg/km ?				

New European Driving Cycle: NEDC
Worldwide harmonised Light vehicles Test Cycle: WLTC
Real Driving Emission: RDE

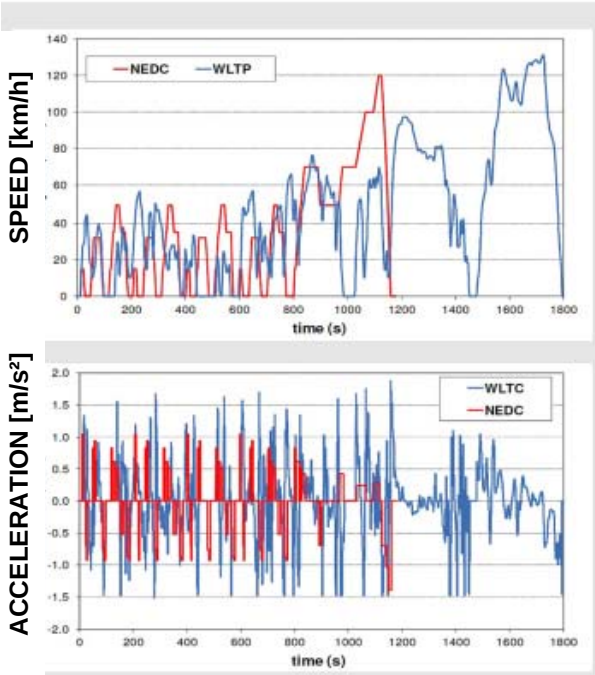
Particle Mass: PM
Particle Number: PN
600,000,000,000: 6e11

Particle and CO_2 emission limits become stricter. Gasoline and Diesel limits will merge.

EU Commission demands RDE/PEMS

"Any engine measure must be applicable to ***all engine working conditions*** to ensure that, in the absence of aftertreatment devices, emission levels in real life driving conditions are not worsened."

Source: European Commission Regulation No. 459/2012 of 29 May 2012 §(7)



	NEDC	WLTC
Distance (km)	11.013	23.141
Duration (s)	1180	1800
Mean vehicle speed (km/h)	33.6	46.3
Maximal vehicle speed (km/h)	120	131
Maximal acceleration (m/s²)	1.04	1.88
Maximal deceleration (m/s²)	–1.39	–1.52
Standstill time (s)	280	227
Standstill proportion (%)	23.7	12.6

NEDC = New European Driving Cycle

WLTP / WLTC = Worldwide harmonized light duty test procedure / cycle

Source: Continental, Dr.-Ing. Detlev Schöppe et al., 34th International Vienna Motor Symposium, Next Generation Engine Management Systems for Gasoline Direct Injection, 25-26.04.13, Vienna

A real-driving test performed by the JRC using PEMS © EU, 2013
Source: http://ec.europa.eu/dgs/jrc/index.cfm?id=1410&dt_code=NWS&obj_id=16180&ori=RSS

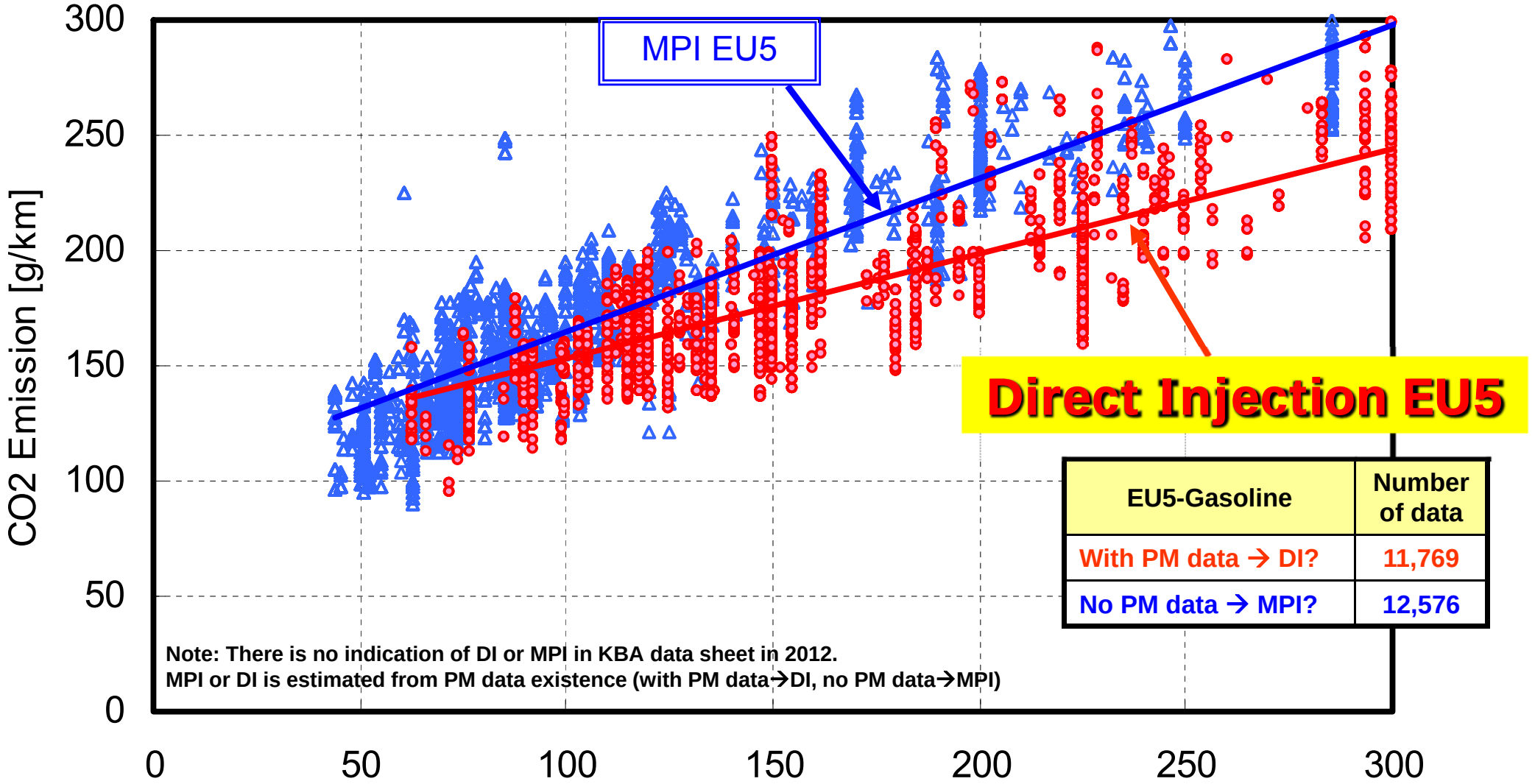
"…it was decided in December last year to ***primarily develop on-road testing with PEMS*** as the main real-driving test procedure. ... The real-driving test procedure …will only become ***fully effective from 2017*** onwards."

Source: http://ec.europa.eu/dgs/jrc/index.cfm?id=1410&dt_code=NWS&obj_id=16180&ori=RSS

RDE = Real Driving Emissions
PEMS = Portable Emission Measurement System

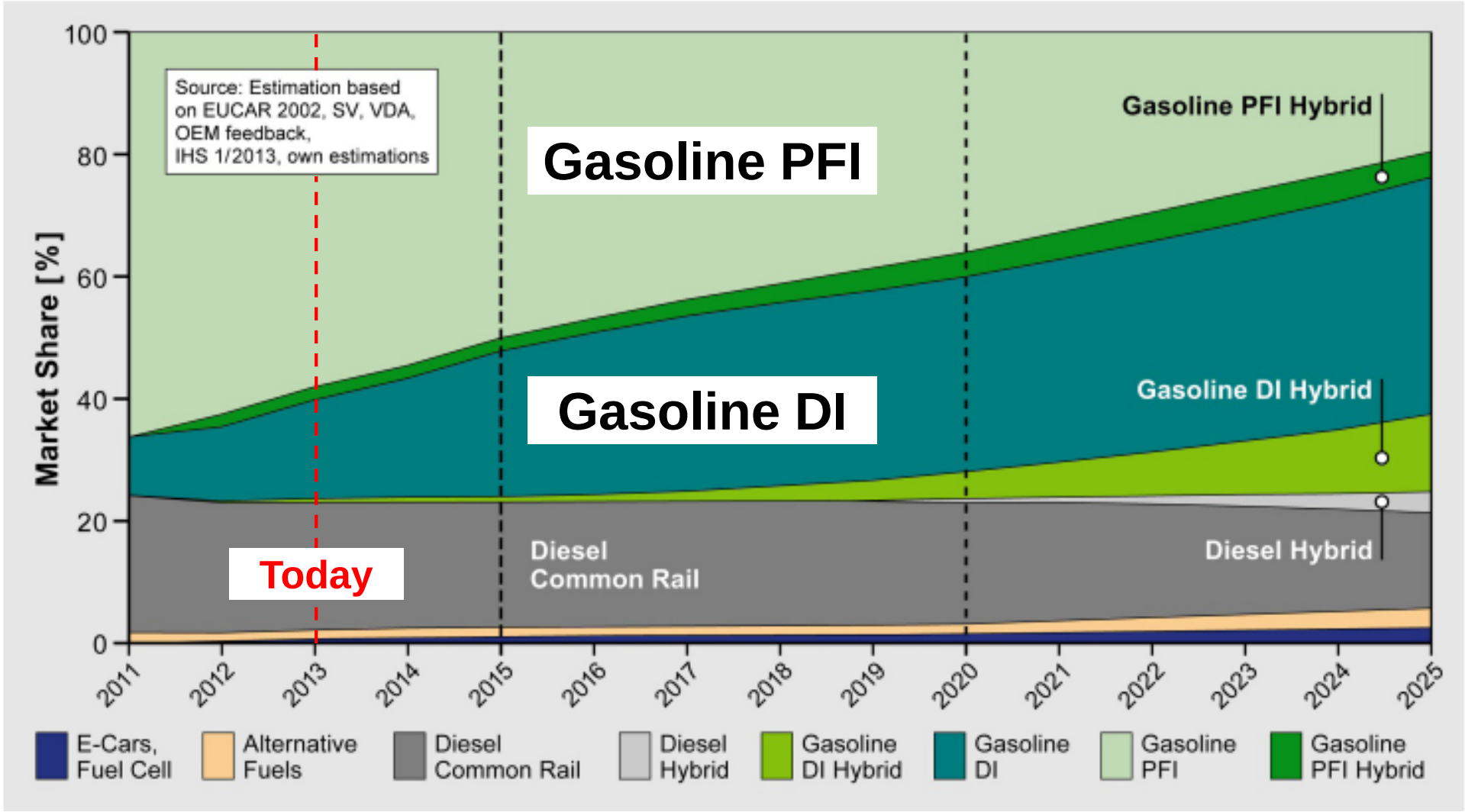
CO_2 Comparison between Gasoline MPI and DI

(source: KBA Mar.2012 data, Passenger car. class M1, certified 2008-2012)



Direct Injection (DI) shows lower CO_2 than MPI.
Approximately 10% CO_2 reduction by DI can be seen at 150 kW condition.

Global Market Trend of Powertrain Evolution



Source: Continental, Dr.-Ing. Detlev Schöppe et al., 34th International Vienna Motor Symposium, Next Generation Engine Management Systems for Gasoline Direct Injection, 25-26.04.13, Vienna

Combustion engines will remain dominant propulsion method in the future. GDI technology will increase in future with downsizing and turbo charging for reduced fuel consumption and CO_2 emission.

Technical Solution for PN and CO_2

Particle Number (PN)
$6x10^{11}$ #/km (Sep/2017~)

Low fuel consumption
Low CO_2 emission

PN reduction
in all operation points
by emission control system

Minimize pressure drop
of emission control system

Low pressure drop Cordierite
Gasoline Particulate Filter (GPF)

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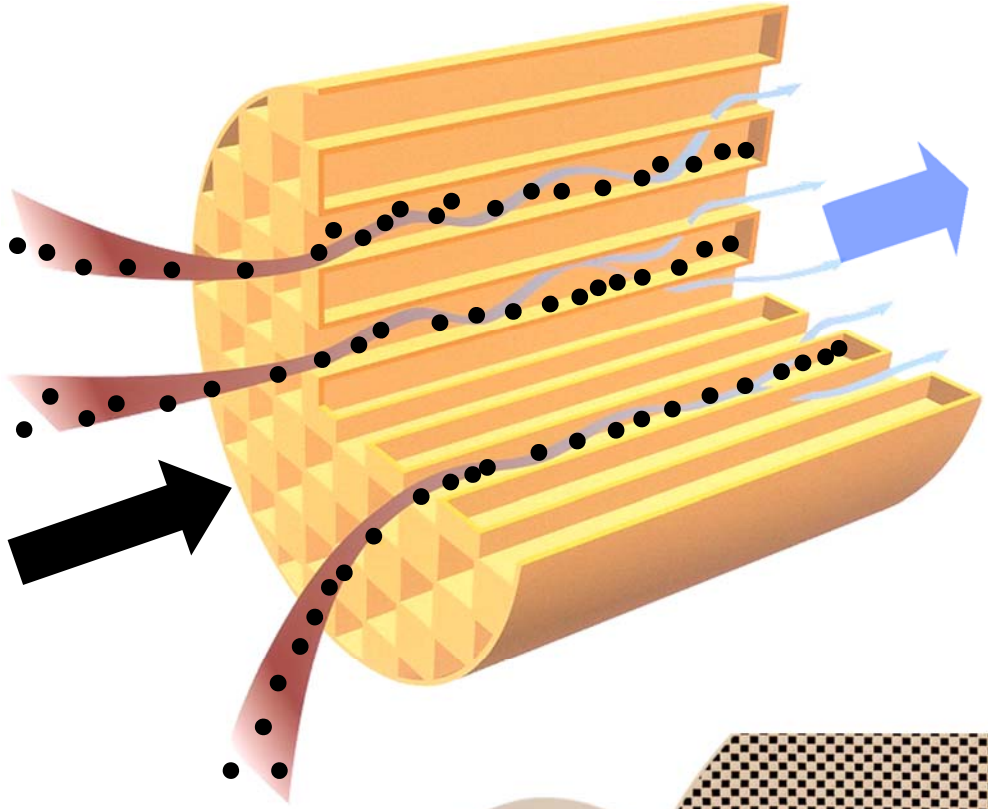
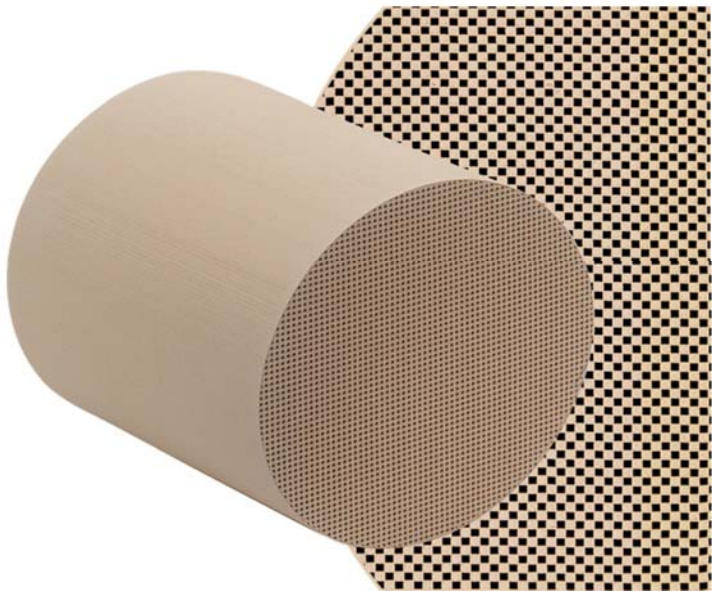
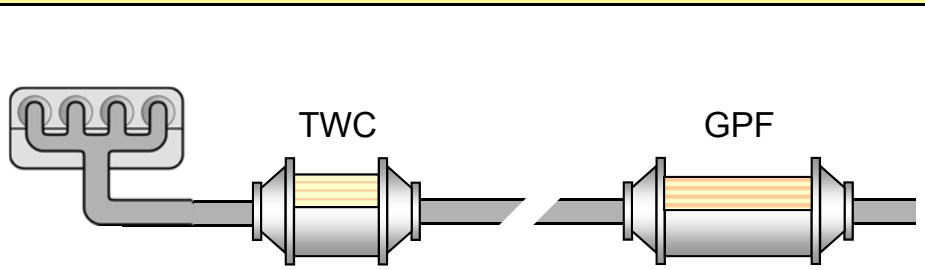
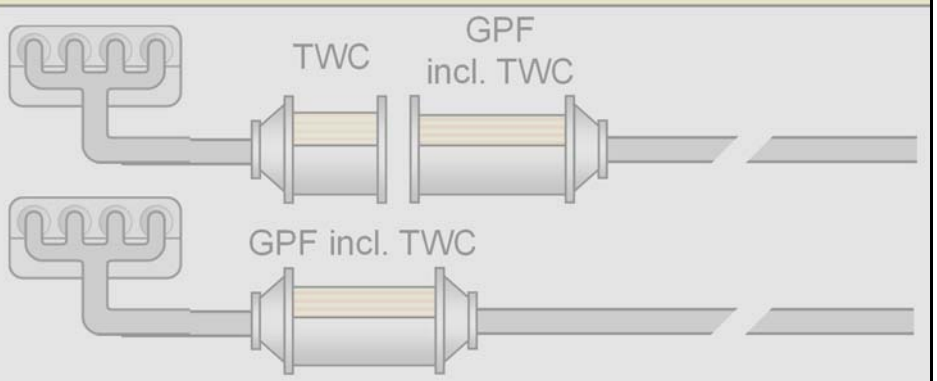
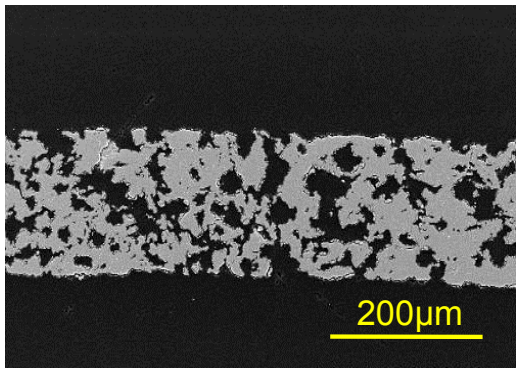
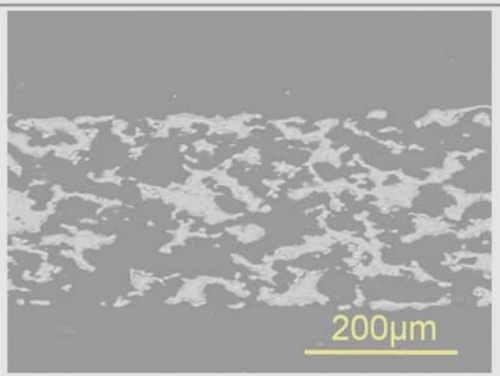




* GPF: Gasoline Particulate Filter

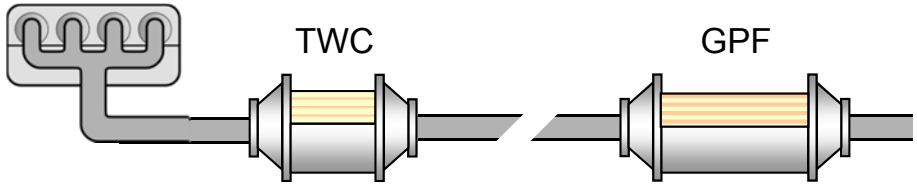
Selection of Suitable GPF Material for any Application

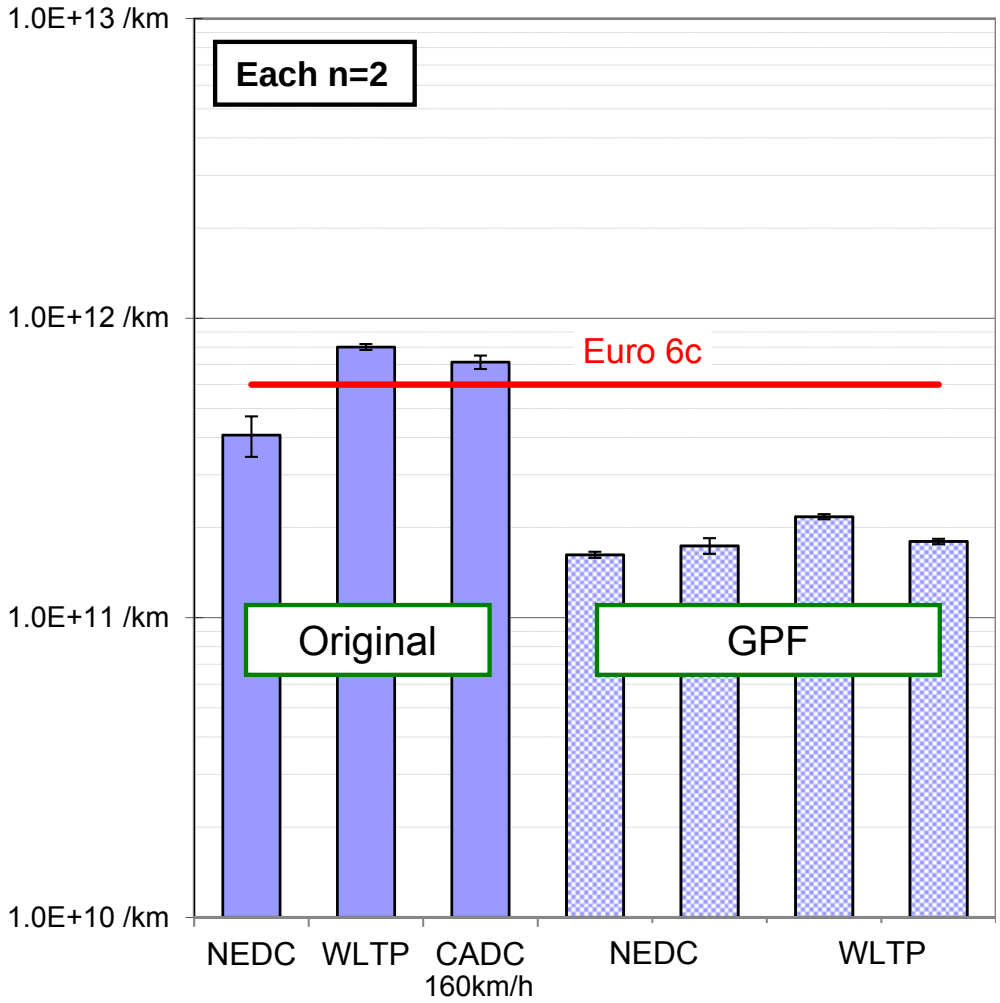
Material	Cordierite Gasoline Particulate Filter	
Porosity	**40-50 %**	**50-65 %**
System Layout		
Micro Structure [SEM]		
Wall Thickness / Cell Density *	**5 mil / 220 cpsi**	**10 mil / 300 cpsi**
	6 mil / 220 cpsi	**12 mil / 200 cpsi**
	5 mil / 360 cpsi	**12 mil / 300 cpsi**
Application	**Add-on type GPF (None/Low Catalyst amount)**	**Replace type GPF (High Catalyst amount)**

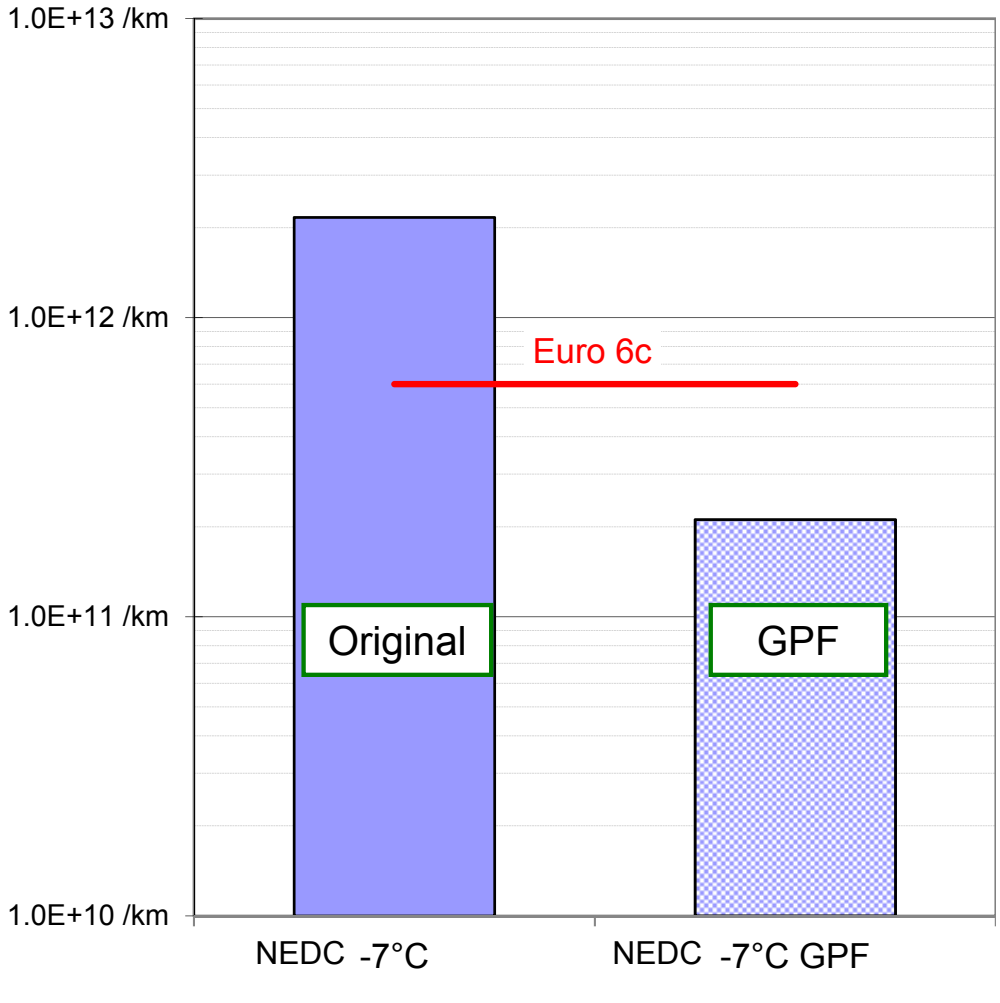
* mil = 1/1000 inch cpsi = cells per square inch

Particle Number Reduction by GPF

Vehicles: 1.4L and 1.8L GTDI λ =1
GPF: ~48% porosity, uncoated
Position: Underfloor



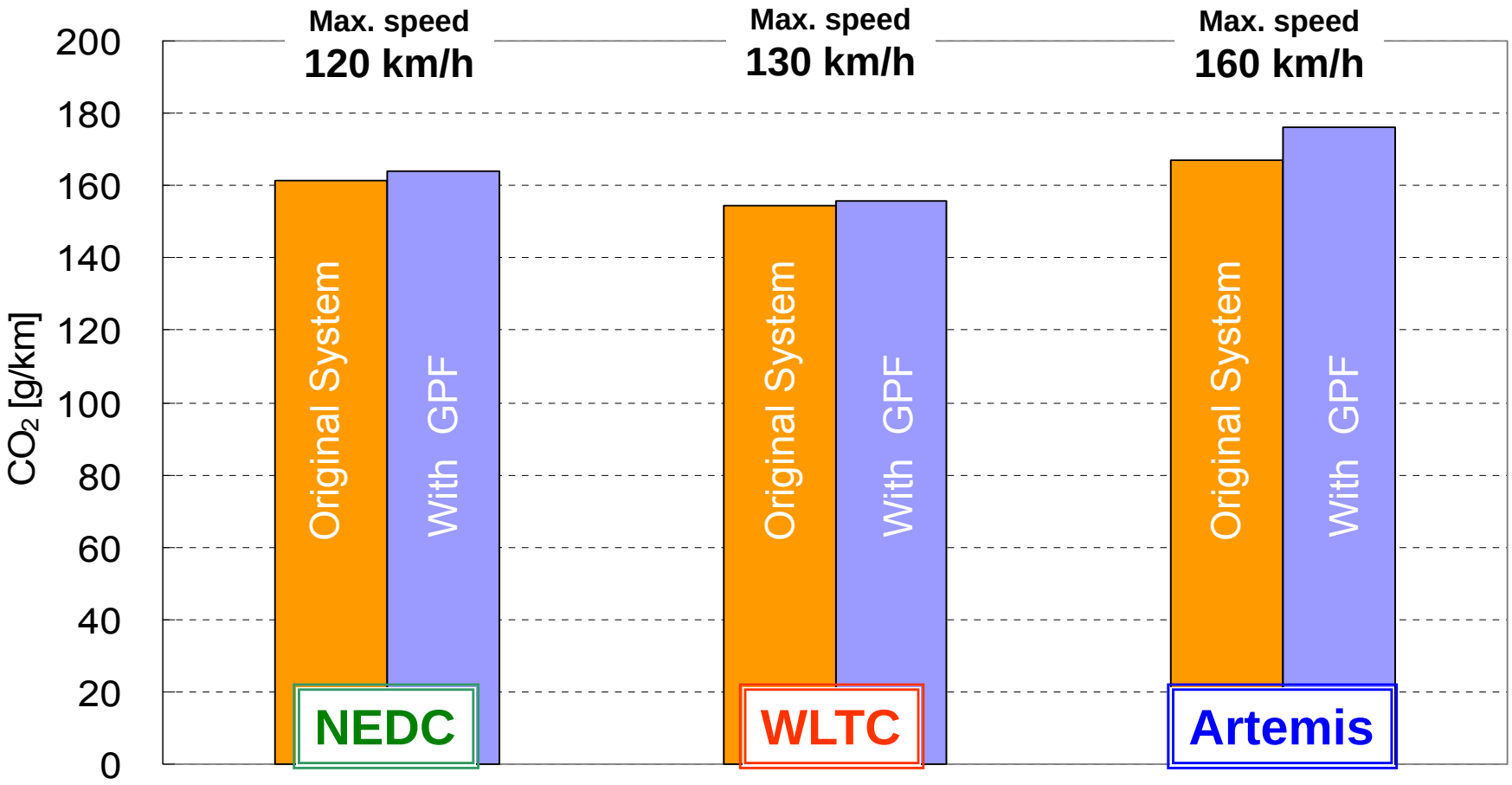




GPF reduces PN significantly in transient test cycles and different ambient temperatures.

Vehicle test results for CO_2 emission

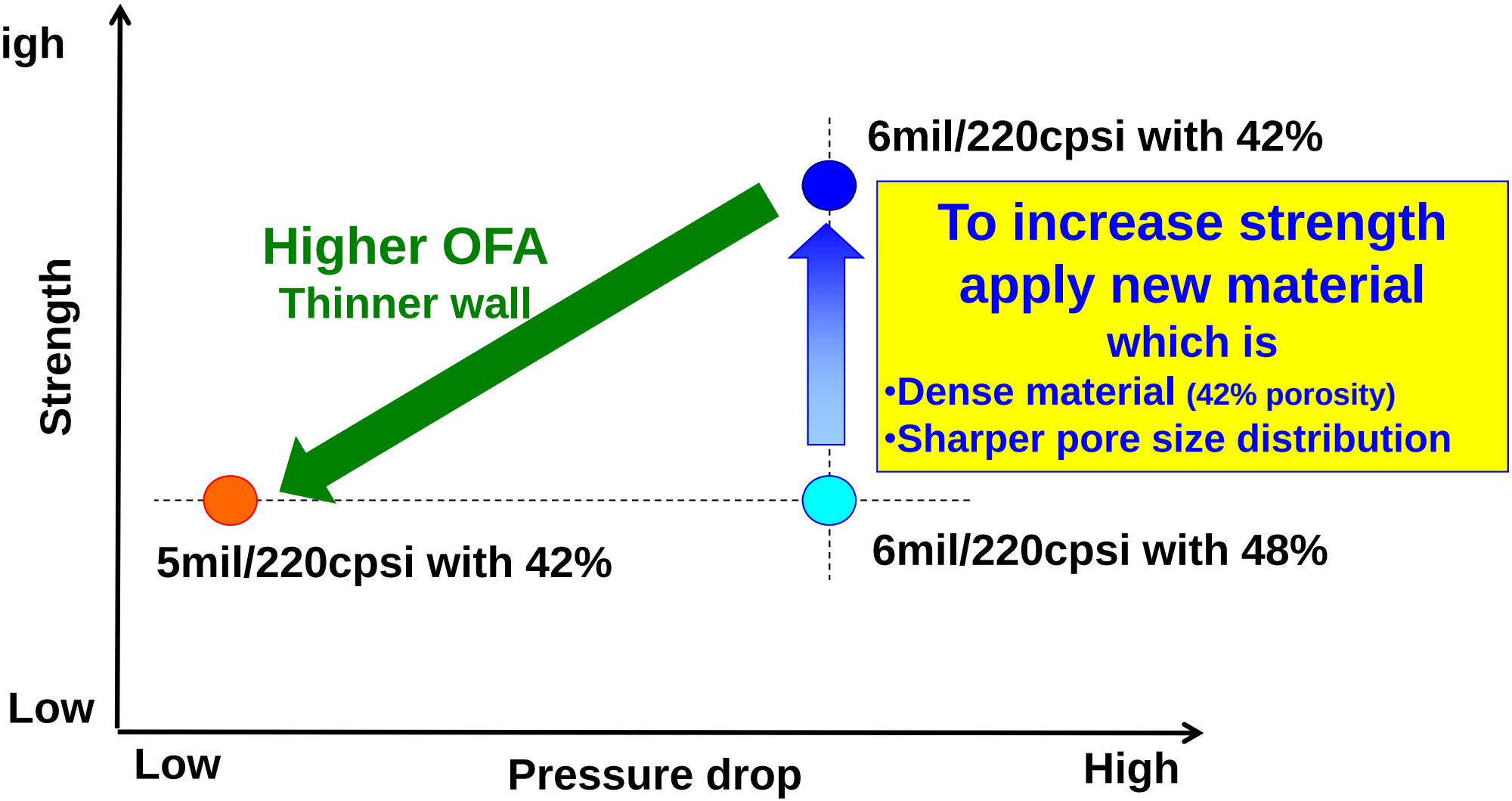
Vehicle: 1.4L Gasoline DI λ=1
GPF: 48% porosity, ϕ118.4 × 127L, 6mil/220cpsi without catalyst
Position: Underfloor



NEDC and WLTC test show no big impact by GPF on CO_2 emission.

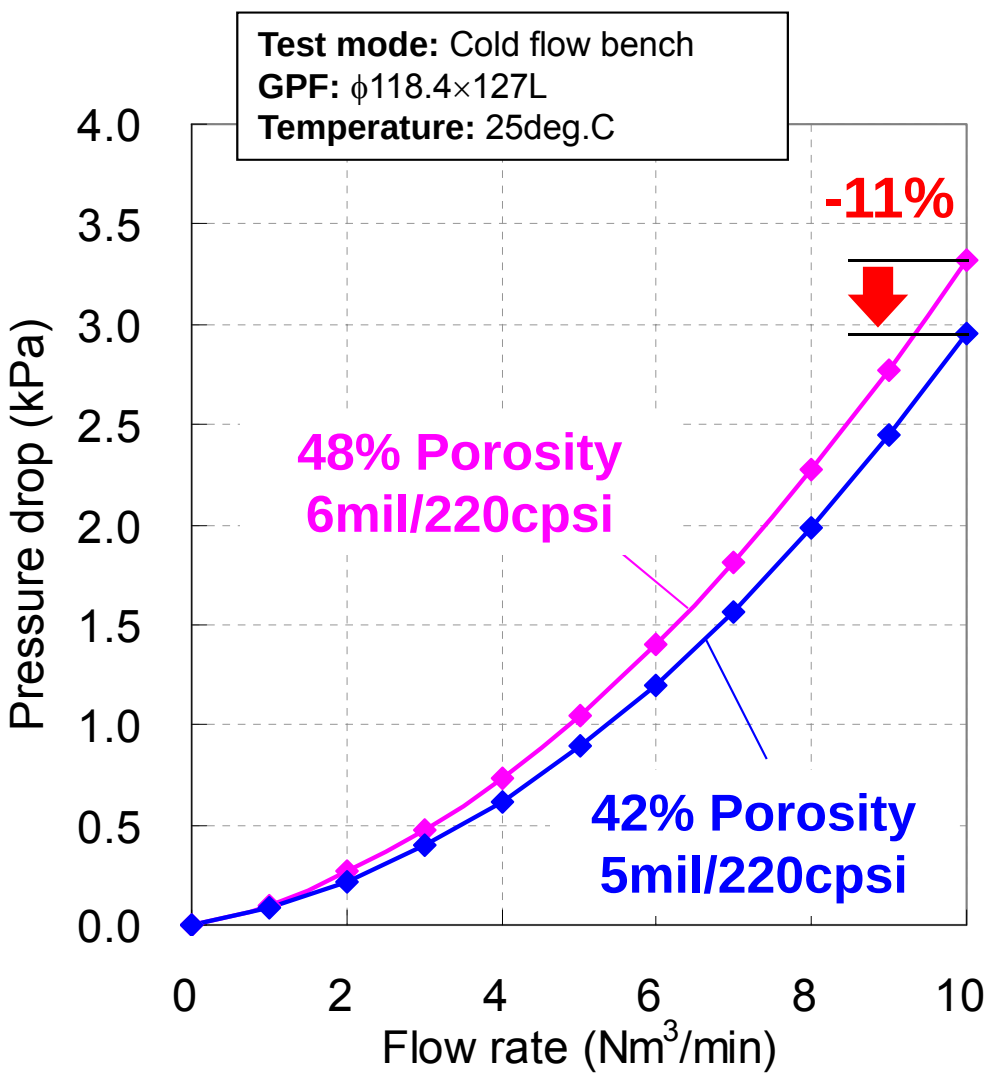
2nd Generation Material Concept - Higher OFA Structure -

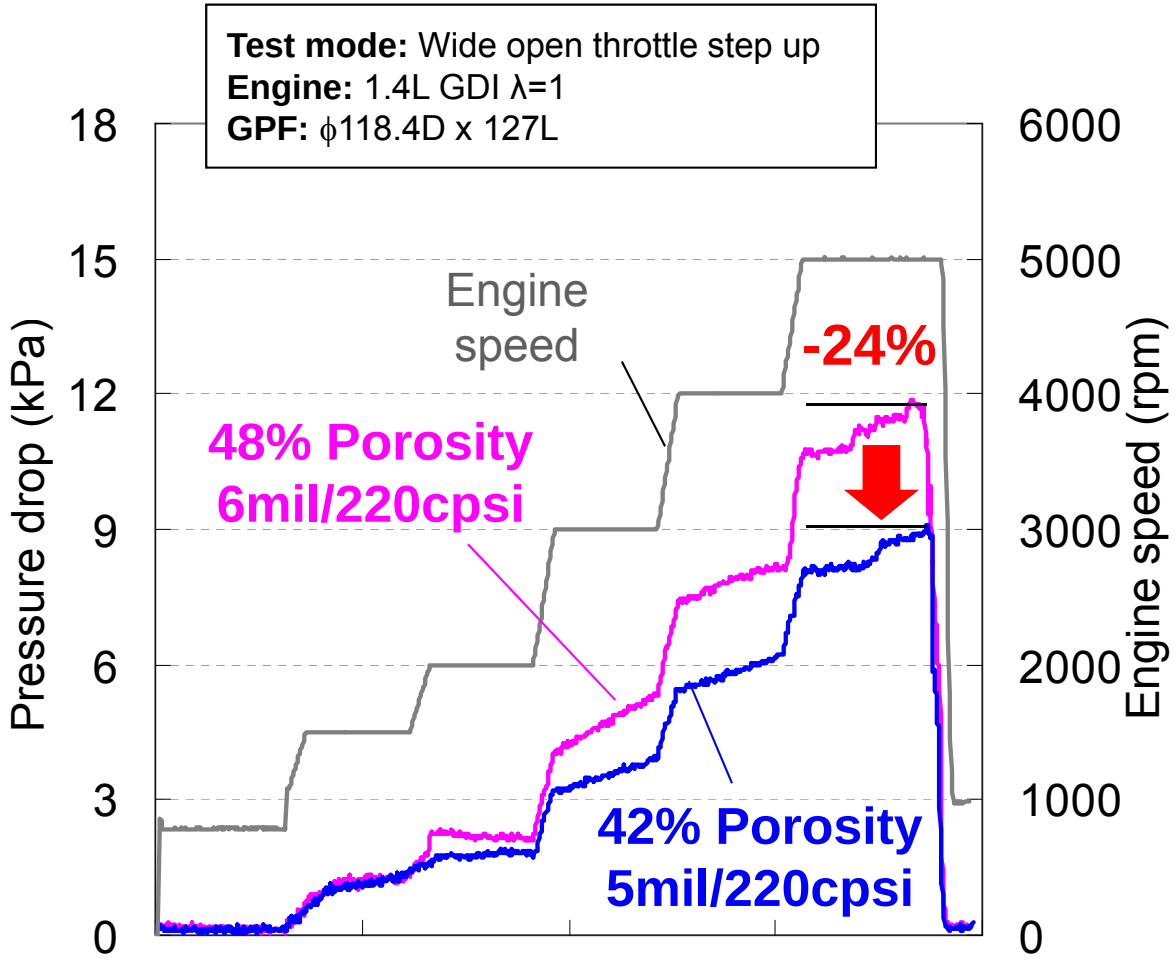
Thin Wall Concept with 42% Porosity



1. Increase material strength by dense material while keeping permeability.
2. Apply higher OFA structure like thinner wall to reduce pressure drop.

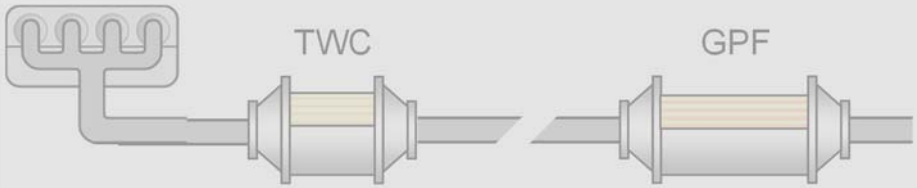
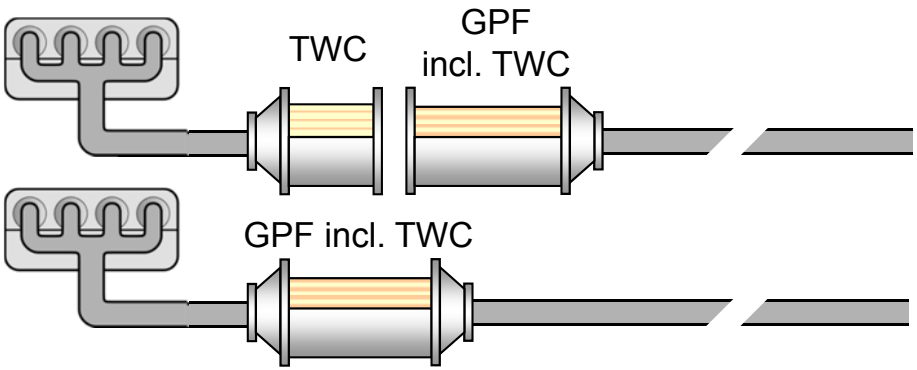
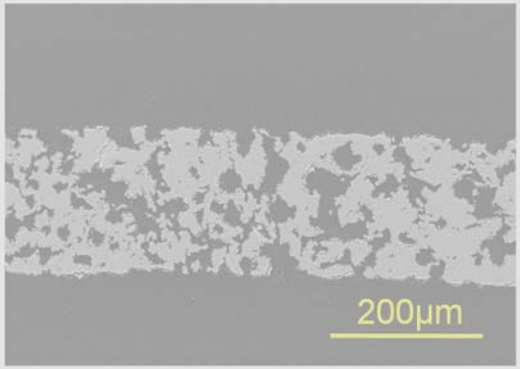
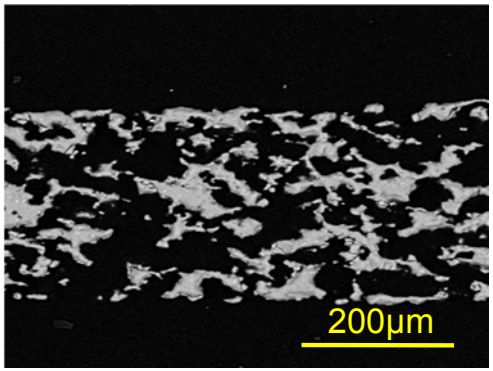
Performance of 2nd Generation GPF Material





New 5mil/220cpsi shows 11-24% lower backpressure.

Suitable GPF Material for un/catalysed Applications

Material	Cordierite Gasoline Particulate Filter	
Porosity	**40-50 %**	**50-65 %**
System Layout		
Micro Structure [SEM]		
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Application	**Add-on type GPF (None/Low Catalyst amount)**	**Replace type GPF (High Catalyst amount)**

* mil = 1/1000 inch cpsi = cells per square inch

Performance of Three-Way-Filter (TWF™)

Comparsion of Performance between

System A: TWF™ emission optimised washcoat

System B: TWF™ backpressure optimised washcoat

DEMONSTRATION OF EU6 COMPLIANT TWF™ SYSTEM

JM Confidential

- Coated NGK 4.66 x 5.5" (1.54L) C650 cordierite filter samples
  - PGM 40/0:12:1
  - Emissions optimised washcoat *vs.* backpressure optimised washcoat
- Oven ageing at 1100 ° C, equivalent thermal load to JM Lean Spike engine ageing cycle
- Evaluation on a 2.0 litre DI EU5 vehicle

EMISSIONS OF BOTH TWF™ VERSIONS MEET EU6

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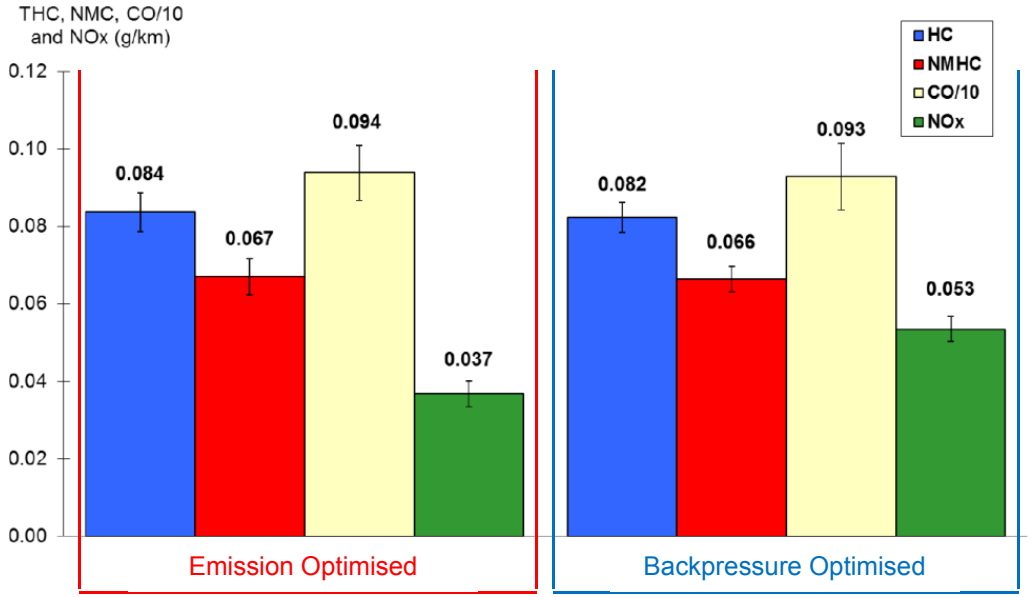

Source: Dr. David Greenwell, 2nd IQPC Conference - Advanced Emission Control Concepts for Gasoline Engines, 13-14.05.2013, Bonn

Both systems can meet the Euro 6c limits for gaseous emissions during NEDC.

Performance of Three-Way-Filter (TWF™)

Comparsion of Performance between

System A: TWF™ emission optimised washcoat

System B: TWF™ backpressure optimised washcoat

BACKPRESSURE AT HIGH SPEED

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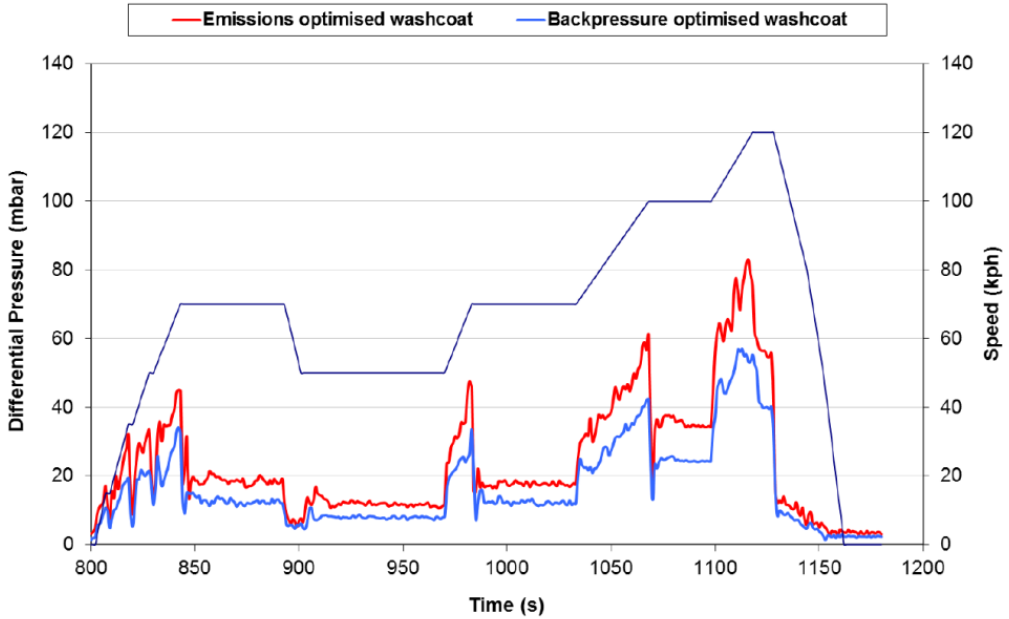

PARTICLE NUMBER

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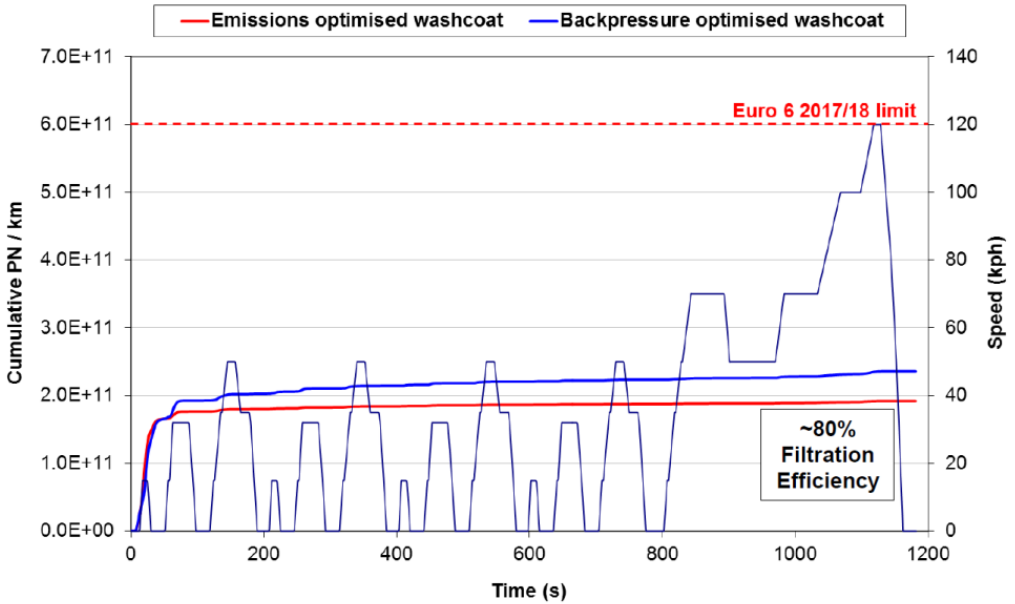

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Both systems can meet the Euro 6c PN limit (6e11/km) during NEDC.

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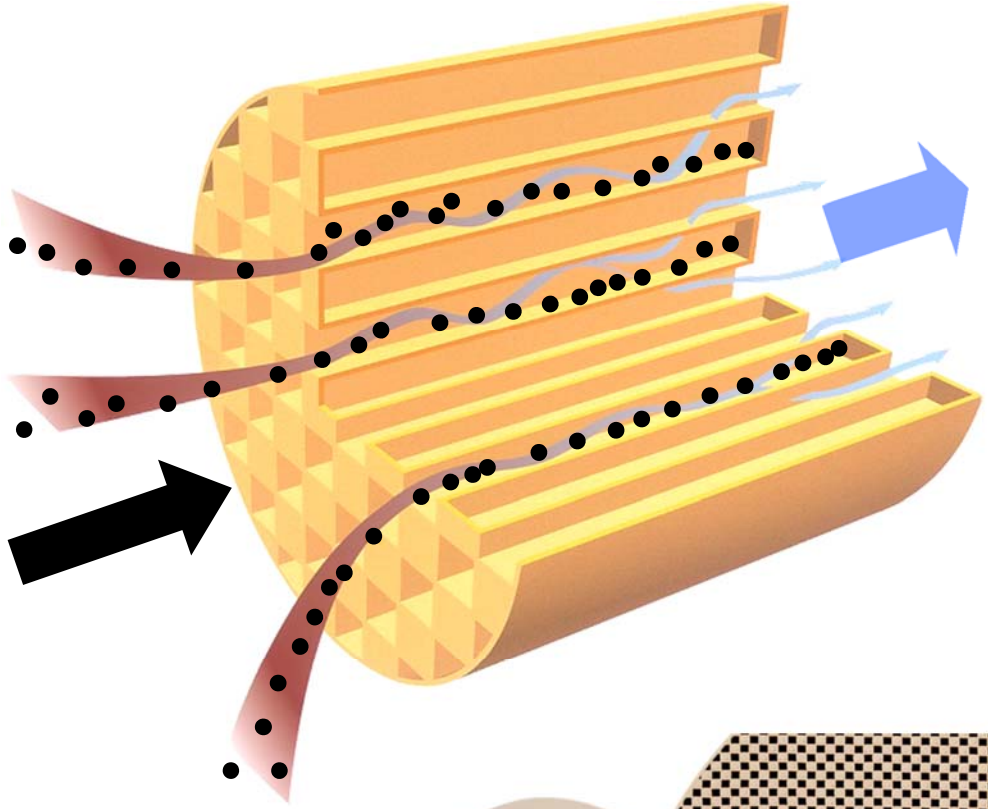

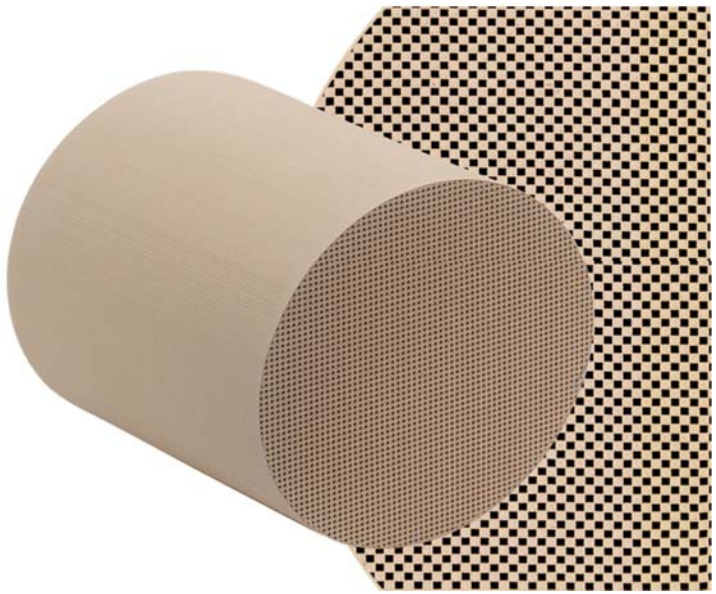

* GPF: Gasoline Particulate Filter

Summary and Conclusion

- There are difficulties to meet PN limits in all test cycles by GDI engine measures. GPF is an effective technology to reduce particulate emission with high filtration performance under all engine operation points and ambient temperature variation.

- NGK developed new robust GPF material with high permeability to enable further reduction of pressure drop using 2nd generation GPF (5mil/220cpsi).

- The pressure drop performance of 2nd generation GPF was confirmed under different engine operation points (11-24% lower Δp).

- High porosity material for catalyst integration is available. Cell structure optimisation and catalyst loading amount are key for low pressure drop.

Low pressure drop Cordierite Gasoline Particulate Filter (GPF)

www.ngk-e.de

Thank you for your Attention

2013 Cambridge Particle Meeting

SAE Technical Papers: 2013-01-0836; 2012-01-1241; 2011-01-0814